How to Scale a Code in the Human Dimension

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Abstract: As scientists' needs for computational techniques and tools grow, they cease to be supportable by software developed in isolation. In many cases, these needs are being met by communities of practice, where software is developed by domain scientists to reach pragmatic goals and satisfy distinct and enumerable scientific goals. We present techniques that have been successful in growing and engaging communities of practice, specifically in the `yt` and Enzo communities.

1 Why "Community?"

Astrophysics, and particularly computational astrophysics, is dominated by vertically-integrated, small-population research collaborations. The concept of a community of researchers – sharing physics modules, improvements to simulation codes, analysis techniques, technology – is somewhat foreign. In fact, this idea of "community" is often viewed as a *detriment* to the individual researcher, rather than as a benefit to the field. I participate in two vibrant, active communities in computational astrophysics, those surrounding the simulation code Enzo and the analysis code `yt`. Within these two communities, we have found a somewhat surprising result: **the empowerment of the community does not come at the expense of individual success.** In fact, with actively shepherded and cultivated community participation and processes, the opposite is true: the betterment of the community comes at the enrichment of the individual.

In addition to the concrete, measurable benefits we receive from community-focused development, we have also realized that **community development is essential to the continued health of the field of computational astrophysics.** By focusing on developing a community of *practice*, where the goals and technology are driven by active participants, we have been able to expand the class of astrophysical problems to which the technologies have been applied. This has led not to consolidation of research interests, but rather a broadening, with improvements, technology, and techniques being directly shared between working domain scientists.

In this paper, I outline the infrastructure and the techniques with which we have cultivated these two complementary, but distinct, communities and the various conscious decisions we have made to ensure their growth and sustainability.

2 Introduction: `yt` and Enzo

The `yt` Project (`http://yt-project.org/`) is an open source, community-developed analysis code for simulated astrophysical data. Largely written in Python, Cython and C, it is parallelized using MPI and OpenMP and has been used to analyze datasets whose size range from small (tens of megabytes) to large (tens of terabytes). `yt` is designed to abstract out underlying technical aspects of simulation data such as file format, units, geometric conventions, and

parameter storage in such a way that is neutral to the underlying simulation platforms. The flagship simulation platforms, where we conducted detailed testing and support all functionality, are are Enzo, FLASH, Orion, Castro, Nyx, Piernik and NMSU-ART. In the current development branch (described briefly below) this has been expanded to include limited support for SPH and N-body codes such as Gadget, as well as full support for Octree codes such as RAMSES and ART. `yt` provides a language for describing physical regions and applying data processing techniques to those regions: rather than focusing on selecting grid patches, particles or octs and then masking out overlapping regions, it develops concepts of geometric regions, regions defined by fluid quantities, and processes that transform those regions into quantitative values. `yt` is best thought of not as an application, but as a library for asking and answering questions about data. This aspect of `yt` naturally encourages technical contributions, as every user of the software package typically writes analysis code that builds upon its underlying machinery. Although its mission has expanded in recent years to include the application of microphysical solvers, standardized input/output data formats, creating initial conditions, and even studying data from earthquake simulations, at its core `yt` remains a tool for interrogating astrophysical data and answering questions about the underlying physics of that data.

The defining characteristic of `yt` is not that it is written in Python, or the operations it does, but rather that it is supported by a participatory community of scientists interested in both using and developing it. The `yt` community draws its members primarily from computational astrophysicists: individuals who conduct and analyze simulations. The first version was written in late 2006 by and for a single scientist, but over the last several years has attracted 170 subscribers to the general mailing list and 50 for the development mailing list; in 2012 it was identified as one of the most highly used codes on the NSF NICS analysis machine Nautilus [Szczepanski et al., 2012]. Over the course of its history, nearly 40 people have contributed changesets, ranging from tiny to very large, and the mailing lists are relatively active, averaging between one and four messages a day. In 2012 we held our first workshop at the FLASH center in Chicago, and we are holding a second workshop in March of 2013 at UC Santa Cruz. Despite this relatively high level of activity for a project in computational astrophysics, the community has faced several challenges as well as taken steps to directly address these challenges.

I am the original author of `yt`, having created it during my graduate school career to analyze and visualize data created by the simulation code Enzo (`http://enzo-project.org/`), an adaptive mesh refinement simulation code. Enzo itself has undergone a number of changes over its years, both in the manner in which it is developed and the problems to which it can be applied. Enzo began as a codebase largely developed by a single individual, but through the stewardship of the Laboratory for Computational Astrophysics (LCA) it grew into a large, open source (but mostly not community-based) development project. A direct consequence of both the technology and the prevailing mindsets led to divergent lines of "public" and "internal" development, resulting in a highly fragmented community of users and developers and many different branches of the code itself. Over the course of a few years in 2009 and 2010, through concerted efforts from the Enzo community, it transitioned from a closed development model with periodic open releases into a fully-open, transparent development model based around contributions from community members. This included resolving many divergent code bases and produced the Enzo 2.0 release. The code is now developed using many best practices of software development including testing, version control, peer review, infrastructure design and investment of stakeholders in the development roadmap. This has resulted in contributions of both physics modules and infrastructure improvements, and has even brought to light bugs that have subsequently been fixed by community members. This transition, from semi-open to community-driven, has brought an energy and excitement to the development of Enzo that seems likely to sustain it for years to come. Many of the items discussed below, about how to shape and foster community, have been applied to the Enzo community as well as `yt`.

3 What is "Community"?

Open Source is often used as a synonym for community development, but in practice they are better thought of as two different, but overlapping, modes of development. The growth of a community, where individuals participate in discussions, report problems, provide enhancements, and support other community members, is neither necessitated by software being open source, nor is it a foregone conclusion for open

source software.

For scientific software, this situation is slightly more complex, as the adoption of open source methods are often met with resistance. In addition to this, members of a given community related to software are just as likely – if not more likely – to be working on similar projects, competing for mindshare among the academic public, and even competing for funding or jobs. Building communities that are able to thrive despite these barriers can result in considerable, non-local benefits: the aphorism "a rising tide lifts all ships" is nowhere more true than in community-driven scientific codes. Even the presence of other, engaged community members means that there are more people able to answer questions from newcomers and provide assistance and energy toward solving problems.

The concept of openness in science amongst academics is something of a paradox. Often, utilizing commodity tools is viewed as a very positive trait, whereas releasing software is occasionally viewed with skepticism. While this is changing, and in some ways quite rapidly, the idea of source code being shared between potential competitors is still often seen as dangerous or even anathema to scientific progress. This typically breaks along three primary objections:[1]

1. Why should I give up my competitive advantage?
2. How can I manage supporting a code?
3. What if someone finds a bug in my work?

Answering these questions in detail is beyond the scope of this document. But, a few comments can be made. **The first two objections to releasing code are directly addressed by a community of practice.** As noted above, the benefits from collaborative, participatory communities can alleviate the burdens of support as well as provide advantages to scientific inquiry that would otherwise not be present. In both the Enzo and `yt` communities, as the community has scaled in size, with it has scaled the number of eager, helpful participants in contributing modules (which are then shared, collectively) as well as provide support for problems and issues on the mailing list. When discussing these aspects of competitive advantage and support, it is also worthwhile to frame the discussion in terms of generalization and specialization. As an example, in the early stages of developing a simulation code, it's entirely reasonable that a single individual can manage every aspect of the code: the IO framework, parallelism, hydrodynamics, gravity, and so on. But as the simulation code becomes larger, more general, and more mature, it becomes unwieldy for a single person to manage and develop all aspect of a code. Within Enzo we have seen this as the code has grown to include many different hydrodynamic modules (including magnetohydrodynamics), chemistry modules, radiative transport, star particle implementations, and parallelism strategies. The overall generalization of the code base has resulted in a deep specialization in some areas of the code. By investing in a community of individuals, the overall management costs are reduced as individuals specialize in different subsections of the code. This pipeline for conducting research using a code such as Enzo shares many characteristics with observational research; the data is constructed using the simulation platform, relies on many pieces of diverse infrastructure such as IO libraries, libraries for parallelism and libraries for solving differential equations, and is then passed on to the analysis platform which processes the data to produce results.

The third objection enumerated above is somewhat more subtle. The implicit question is not, "What if someone finds a bug?" but really "What if someone sees my work and is able to show that it is flawed?" This objection is the most challenging, as it neatly aligns with the conflict between personal advancement and the collective advancement of science. The glib, simple solution to this would be to prioritize an incremental, layered approach to science rather than preserving the professional benefits of previous, potentially incorrect results. In this approach, "bugs" and flaws in results are not hidden from view and defended from exposure, but rather found and corrected. Unfortunately, such prioritization is a subtle form of the prisoner's dilemma: it is maximally successful when all members of the community participate in revealing shortcomings and problems. The personal solution is somewhat more subtle, and not entirely clear. From a pragmatic perspective, identification of bugs enables higher-quality, longer-lasting results, less likely to be overturned by subsequent investigations by competitors.

As computational science matures, and as computational techniques permeate every aspect of scientific inquiry, it is natural that the software utilized in scientific inquiry grows more complex. Scientific software in many respects, particularly in astrophysics, is thought of as something of a second-class citizen – in years past, the concept of scientific software being de-

[1] For a broader and more quantitative study, see Stodden [2010]

veloped in isolation, placed on a website and largely abandoned became pervasive. This methodology simply will not scale with the complexity of projects necessary for modern scientific inquiry; we have reached the age of advanced algorithms being applied in non-trivial ways to complex, physically-rich datasets. The cyberinfrastructure necessary to address problems in computational science is no longer tractably solved by individuals working in isolation – community projects must become the new norm.

Part of the reason that communities developed around scientific codes can be beneficial is also a component of the challenges within these communities. An active community with participants sharing enhancements, features, and assistance relies on the participants developing those enhancements and understanding the code base well enough to provide assistance to less experienced individuals. Scientific code development is strongly driven by pragmatic, short-term needs of scientific inquiry; as a result, most improvements are motivated by the next paper, or the next talk, or advancing a particular line of inquiry likely to result in a publication and the affiliated respect from peers for solving a challenging scientific problem. The common argument against sharing advancements, techniques and tools is that it undercuts competitive advantage. This form of individualism results not only in researchers refraining from sharing, but more importantly, prevents them from benefiting from the work of others. A strong community of sharing results in a stronger technical code base, even if it has the side effect of a moderate reduction in perceived intellectual priority for individual researchers. If I share a technique that can be applied to Population III star formation simulations, I can no longer be the only one to apply that technique – and thus the only person who can answer that type of problem. I lose a small amount of intellectual priority. However, I am now able to receive improvements to the technique, suggestions for further enhancements, and am thus able to extend my scientific inquiry further than before. The most important aspect of this is that altruistic goals (sharing, reproducibility, openness) align exactly with non-altruistic goals. It does not matter if I share because I hope to gain something in return or because I believe in openness; the end result is that the *health of the community* has been improved by participation.

The strongest bias we have seen in `yt` is not against releasing of code or contributing back, but against the notion of conducting any development at all – whether that be contributing code, documentation or even reporting bugs. This cognitive block comes from a fundamental misunderstanding of how scientific codes are developed, one that we have been attempting to remedy within our own ranks. The traditional view of open source scientific code development has been that of two groups – developers and users. This segregation of individuals results in an implicit, but difficult to overcome, feeling of boundaries between responsibilities. Often responsibilities such as verification of results, inspecting results, and tracking (and understanding) modifications to the code base are left to "developers." Unfortunately, all of these responsibilities are essential components of the scientific method! Segregating responsibilities in this way leads to misunderstandings about the nature of scientific codes, many of which are constantly under development and improvement, and the nature of the results that they can produce. This is even evidenced in simple things such as using the word "user" to describe community members, further emphasizing a distinction between people who "use" the code and people who "make" the code. In Pawlik et al. [2012], the authors thoughtfully describe the role of scientists in software not as a black and white, user or developer distinction, but rather as a continuum of greys. Often, the self-application of a term like "user," with its connotations, results from self-assigned roles, or perceptions of individual abilities. As peers in a global scientific community, **the distinction between "users" and "developers" is actively harmful**, when in reality scientists are tasked with occupying that grey area in the middle.

In both the `yt` and Enzo communities, we have seen this behavior play out numerous times. Those members of the community who have been the most giving of enhancements, assistance, and technology (scripts, modules, bug fixes) are typically those who are able to best take advantage of the technology to ask complex questions about the physical world. Furthermore, the process of opening up a module and contributing it to an open source software community provides the opportunity for receiving enhancements in functionality, bug reports, and synergistic applications of that module.

In the `yt` project, there are a number of individuals who are the primary contributors and a larger number of individuals who have provided occasional bug fixes or individual, isolated modules. The influence of non-developing community members on code changes, roadmap efforts, and development method-

ology is not only allowed, but encouraged and *solicited*. Furthermore, we actively solicit contributions in the form of scripts, modules, and enhancements or modifications to the `yt` codebase. This initiative has resulted in several positive effects, all of which have strengthened `yt` as a *community*, independent of their effects on `yt` as *software*. Individuals who do not feel motivated to or capable of contributing in a technical sense are more likely to contribute through helping other users, providing documentation, and even networking and advertising the project. But the more prominent effect is a sense of investment in the project. This sense of investment results in quantifiable results (such as more mailing list activity, a larger number of commits) as well as results that are more difficult to quantify, such as positive feelings, friendly discourse, excitement, word of mouth, and so on.

4 Challenges

Even beyond these concerns, community building can be challenging within the confines of the traditional realm of academia. The reward structure in astrophysical academia, for funding, jobs and mindshare, is highly-correlated with influence, high-impact papers, and citation counts[see also Howison and Herbsleb, 2011]. Often developing software, or participating in academic communities, is seen as orthogonal to these goals, even though this is not necessarily true. In light of this, soliciting development contributions is particularly difficult. Developing a tool in support of a publication (for instance, a module for `yt`) is seen as a worthwhile use of time. Despite the benefits that come from making that tool available, the time needed to "clean it up" and provide a modicum of support is not as immediately beneficial, as it does not result in an additional publication, additional citations, and so on. Often, those contributions that would be the most beneficial to the project as a whole are the most difficult to motivate. These secondary, yet important, goals include improvements to documentation (particularly narrative, instructive documentation), testing of individual components (as opposed to large-scale integration testing), and infrastructure improvements such as optimization and maintainability refactoring. As a result, tool builders are not always favored by the academic reward structure. This is not unique to computational astrophysics, but is also seen frequently within the instrumentation community. A common pattern seen within `yt` is a spirited discussion of idealistic goals for the project, but then pressing deadlines and other local concerns typically temper enthusiasm and execution. I myself am not only guilty of this, but perhaps the most common instigator!

The challenge to community building I find the most worrisome is that presented by the so-called "citation economy" in astrophysics. The influence of a given piece of code is often measured by citations to a method paper, which is by definition a fixed and archived document. In 2011, a method paper for `yt` was published. Enzo's method paper is still under preparation, but papers in 1997 and 2004 are often cited as references for Enzo. Because ADS provides reverse-indexing capabilities, the number of citations to these papers provides an immediate method of gauging the influence of the software that they describe. In the intervening time between publication of the method papers, new contributors have joined the collaborations and contributed substantial and non-trivial enhancements to the code base. In fact, this is not only what has already happened, but an explicit, named goal of the future of these two code bases! This results in an unfortunate conflict of interests between new contributors and existing contributors. It is in the best interests of existing contributors, who contributed to the code base prior to the publication of a method paper, to consolidate citations in the canonical paper; unfortunately, it is in the best interests of new contributors to publish a new method paper, so that they can begin to "collect" citations. In whose interest is it to contribute to a code base without rewards mediated through citations, one of the most common metrics of success in academia? I believe this is among the greatest challenges to community developed codes in astrophysics, one that will continue to grow in importance as software projects inevitably scale beyond a handful of contributors[2].

5 Strategies

Not all of the challenges enumerated above can be addressed directly. However, in both the `yt` and Enzo communities, we have addressed the technical and social challenges through conscious development of infrastructure and techniques. These have been de-

[2] Alternate metrics of software citation are being explored by, e.g. the ASCL [Allen et al., 2012], but they primarily address discoverability of codes and do not attempt to address the issue of distributing credit to contributors.

signed to foster good will, encourage contributions, and build social capital between contributors. Below, I list several steps we have taken over the last several years toward the goal of growing and engaging communities of practice.[3]

Most important, however, these need to be viewed as the investment they are. These strategies, particularly the social strategies, require not only focused energy and time, but an emotional investment. **You must design the community you want.** This design extends far beyond designing software and algorithms; it includes thinking about the diversity of contributors and community members, the tone of discourse within the community, the projected enthusiasm within the project, and even the congeniality with which feedback – especially critical feedback – is received. The culture seeded in a community will self-propagate; whether this is a culture of neglect, a culture of homogeneity, a culture of kindness, a culture of brash arrogance or even a culture of openness, this will flow outward from the core[Bacon, 2009, Trapani, 2011, Allsopp, 2012]. Both Enzo and `yt` have attempted to build cultures that promote respect and excitement.

5.1 Technical Infrastructure

Within both `yt` and Enzo, we utilize several pieces of technical infrastructure that ease the process of growing communities [see also Fogel, 2005]. These include open and freely-joinable mailing lists, a completely open development process based on the distributed version control system (DVCS) mercurial, and a code review and mentoring process to ensure contributions are high-quality, with a minimum of friction. Furthermore, we utilize methods of communication that enable participation and that are tuned for low- to high-latency interaction.

Both `yt` and Enzo have seen an enormous growth in contributions following migration to DVCS; this is not unique to these projects, but is a hallmark of the lowered barrier to entry presented by DVCS. In contrast to centralized version control systems such as CVS and Subversion, DVCS systems are fully-distributed. Every clone, or checkout, of a repository is a peer with every other clone; this enables anyone who checks out a repository to track their own changes to the repository, and provides the (technical) ability to much more easily contribute changes upstream. The unique versioning of local copies of a code base also allow unique revision specifiers to be applied globally; rather than "version 4.2 with modifications (unspecified)" code that generates a given result can be uniquely identified with a globally-unique hash. Both `yt` and Enzo are hosted on BitBucket, a code hosting provider (roughly functionally equivalent with others such as RhodeCode, GitHub, Gitorious and Savannah). It provides technical infrastructure for code review, accepting changes, tracking contributions and identifying specific revisions of the code. By using this system we lower the barrier to entry for contributors, enabling submission of locally-developed changes. By using DVCS, we encourage scientists using `yt` or Enzo to track their *own* changes to it. Even if this code is never submitted for inclusion in the primary repository, this enables provenance tracking and debugging.

Development of scientific software also requires several difference degrees of communication; as the software itself is not the only project contributors are working on, we have found that communication is naturally divided into three categories, based on latency and urgency. Immediate communication, such as in-person meetings (or "code sprints") or Google Hangouts, are useful for low-latency planning, discussion, and collaboration. Tools such as Internet Relay Chat (IRC) provide a means of medium-latency communication; often in the `#yt` channel on FreeNode, an IRC network, between 10 and 20 people can be found at any time. Messages left here are usually responded to relatively quickly, which leads to a low-latency discussion where problems can be resolved much more quickly than through email. Finally, nearly all planning and detailed discussion happens through high-latency mediums such as comments on code changes and mailing lists. The mailing lists for `yt` (which are titled the unfortunately-chosen names `yt-users` and `yt-dev`) are open, indexed by Google, and freely joinable. We have often (successfully) encouraged discussions here to turn into collaborations and code sharing, and in fact we have had a number of successful opportunities for long-term planning and invasive code changes here. They serve not only as broadcast media, but as venues for soliciting input and contributions.

Nearly as important as providing mechanisms for communication is reducing the barrier to entry for new contributors. This includes ensuring a

[3] A related work is Prlić and Procter [2012] where the authors have compiled a set of very useful and helpful guidelines for scientific software development.

smooth process to finding the appropriate location in the source code, making changes, submitting those changes for review, and a kind, thoughtful mentoring process for new code contributors. The most common path we have seen for new code contributors is relatively straightforward:

1. Individual applies software package to meet own goals
2. Individual develops a modification to the code, for either an enhancement, a bug fix, or a contribution of an example
3. This change is submitted for inclusion in the main `yt` repository
4. The change is read, reviewed and tested by community members to ensure that standards for coding, documentation and testing are all met.
5. The individual begins to participate in the community

The main codebase is not suitable for contributions of all types; we have found individuals eager to contribute scripts that exist as supplemental tools, or that were used in the writing of a paper. To support this desire, we provide a location (`https://hub.yt-project.org/`) to submit these scripts as well, where links to external source code repositories are collected alongside descriptions of the individual projects. In this way, by providing mechanisms and structures, as well as an open and active solicitation for technical contributions, we have found that we can foster a sense of community and accomplishment among individuals.

We have found that even minor barriers to contribution (or even software deployment!) can build up a "technical friction" to participation that results in losing contributions and community members. In an effort to alleviate this, we provide easy access to the source code, detailed instructions for contributing code, a mechanism for communication, and scripts that assist with the entire process. We have found that by ensuring that we have a uniform review process (where even code written by founding members of the community is reviewed) we ensure that the code is of acceptable quality, tests are included, and that undocumented code is discouraged.

5.2 Social Techniques

In Fitzpatrick and Collins-Sussman [2012] the authors describe a strategy for social interactions among so-called "geek" teams. I will not provide a detailed retelling of this, but despite focus on applying the techniques described in the book to software engineers, in many ways they can be applied directly to collaborations around scientific software projects. The authors enumerate three characteristics which they suggest applying to all communication and interaction:

- Humility
- Respect
- Trust

Communication by text, in particular about technical topics, is often stripped of the nuances and inflections that convey emotion. In textual media, therefore, it is even more important to guide discussion in a way that encourages participation. Within the `yt` community, we are very careful to ensure that the tones on the mailing list, code review and in IRC should be conducted in this way: the health of a community can be judged by how it treats newcomers and novices as well as how it treats experienced, advanced participants. Even in framing analysis interactions between peers in this way, one can see how communication can serve the growth of scientific communities. In scientific software communities, an aspect that often goes unmentioned is that we arguably want to foster discussions between *peers*, not discussions between an elite class and a subservient class. By guiding the discussion with a focus on humility, respect and trust (HRT as abbreviated by Fitzpatrick and Collins-Sussman), discussions can become more congenial, more productive, and can lead to a greater spirit of collective focus.

Humility can be well-characterized in how a community responds to negative feedback. In a community in which I participate, I witnessed a discussion between an experienced community member and a newcomer. The newcomer reported what they thought was a bug in a particular routine. The experienced community member, who had made the change that introduced the potential bug, responded with a very abrupt, dismissive response. "It's like that for a very good reason. Don't touch it." By terminating discussion at that point, it sent the clear signal that a discussion of the reasoning behind a code change was simply not necessary; the message was not only that the reasoning was beyond reproach, but that a discussion was not worth the time it took to have. The better solution, of an open and humble discussion of the background and reasoning behind the decision, would have been to engage the newcomer and explain the reasoning behind a decision. This takes an investment of time, but certainly no more

than the investment of time it would take to justify such a decision to a referee or journal reviewer, and the potential gains in this case would be a new contributor and an increase in social capital amongst the community.

Respect can be seen in how peers contribute to the development of the code. In principle, when developing a scientific code, we are engaging in scientific discourse, attempting to push the field of astrophysics forward in both our understanding of and our ability to ask questions of the natural world. One of the most common ways I've seen this ignored is when a person writes to a mailing list or appears on IRC and says some variation of "I've noticed something is acting strangely with ..." The all-too-common response is simply, "You're doing it wrong," or even worse, a dismissive instruction to "Just read the documentation." This is rarely even prefaced with the obvious question of, "How did you expect it to act?" It terminates discussion and discourages individuals from returning. This has the direct effect of reducing participation, and disproportionately impacts new contributors. A lack of respect can infect and transform a community into an unfriendly, unwelcoming environment; the most valuable attribute a community of scientific software developers has is its ability to engage in scientific practice, and that is obstructed by a lack of respect.

Trust within scientific software communities is perhaps more subtle. What we have seen with `yt` and Enzo is *not* that trust is an unwavering faith in someone to produce high-quality, scientifically correct code, but a trust in the process and the stewardship of a code. Within communities of scientific software, we have seen this evidenced when contributors *let go* of a project. As a community matures, individuals cannot contribute to the breadth of sub-projects that they did when it was young; furthermore, as scientific interests shift, the leader of an individual project or aspect of the scientific code may move on to other things. *Trusting* that the community will be able to steward and shepherd that project is a crucial ingredient in addressing sustainability and burnout, and an essential ingredient in expressing trust for peers and other community members.

The motion of projects between individuals is a difficult social situation. We attempt to address this in `yt` by emphasizing *pride* over *ownership.* **By changing the conversation from dominion to stewardship, this changes how individuals approach projects, and helps enable them to regard external contributions in a positive way, rather than as threats to their accomplishments.**

HRT are not always easy attributes to focus on. Particularly in a competitive field such as astrophysics, it can be difficult to spend time thinking about how words or conversations will be perceived, particularly when these conversations are between potential competitors. But by remaining focused on engaging community members as peers, treating them with HRT and spending time and energy on thoughtful communication, the community will be more likely to grow and flourish.

6 Conclusions

As computational science has grown both more complex and more pervasive, communities of practice surrounding scientific software projects have become essential to the health and vibrancy of computational science projects. Unfortunately, the academic reward system does not always align with the development of software projects, which can lead to stagnation or corner cutting in important tasks such as infrastructure, documentation and testing. This largely results from the overlap between the traditional roles of developers and users in software development, a distinction that can in fact actively harm the scientific process.

To grow communities around any software project, the structure and character of the community itself must be carefully considered; you must *design* this community. This includes setting the tone of discourse, consciously fostering a diverse set of participants, and being open and enthusiastic. This process can be assisted with technical infrastructure. This includes using distributed version control systems, conducting open communication in media that suit the style of communication, and streamlining the participation process and providing a clear method of contributing. Technical infrastructure alone cannot "solve" the development of a community; social infrastructure and standards of conduct must also be developed. Conducting business while remaining focused on humility, respect and trust can help to ensure that newcomers feel welcomed, existing contributors and peers feel validated and respected, and that ultimately as interests change over time projects do not stagnate under the weight of code or project ownership.

A vibrant, active community brings sustainable development, synergistic applications and develop-

ment of code, and considerable rewards in potential collaborations and discourse. I am grateful for the opportunity to have participated in both the `yt` and Enzo communities, and grateful for the concrete rewards – scientific, social and technical – that my participation has allowed me.

As a closing note, despite all of the successes we have seen in the `yt` and Enzo communities, we still have considerable room to grow from both the social and technical standpoints. I hope that as communities driven both by long-reaching goals and the pragmatic needs of scientific inquiry, we can continue to remain healthy, vibrant and growing. I believe that the single biggest problem within scientific software communities is ensuring credit for community participation can be shared with new contributors. This affects motivations at essentially every level, and because of its very nature can dramatically affect the health and stunt the growth of scientific software communities.

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